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SUBMERGED-ARC NARROW-GAP WELDING OF HEAVY SECTIONS

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PHYSICAL METALLURGY RESEARCH LABORATORIES

REPORT: ERP/PMRL 83-42(TR)

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by

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ABSTRACT

The following work constitutes the first progress report on the use of a square wave AC/CP power source that has been installed at PMRL. The preliminary results show that this power source can be used successfully for submerged-arc narrow-gap welding.

LABORATOIRES DE RECHERCHE EN MÉTALLURGIE PHYSIQUE

RAPPORT PRE/LRMP 83-42(TR)

SOUDAGE À L'ARC SOUS FLUX AVEC FAIBLE ÉCARTEMENT DES PROFILÉS LOURDS

par

R.S. Chandel, R.F. Orr et J.A. Gianetto

RÉSUMÉ

L'oeuvre suivante met en évidence le premier rapport du progrès obtenu lors de l'utilisation d'une onde carrée de la source d'énergie CA/PC dont l'installation a eu lieu aux LRMP. Les résultats préliminaires font preuve que cette source peut s'utiliser, avec un égal succès, pour le soudage à l'arc aux écartements étroits des profilés lourds.

INTRODUCTION

The basic concept of narrow-gap welding is to join heavy sections by welding in a parallel or near parallel sided gap, 12-20 mm wide, normally using a one-sided welding technique (1).

The need for the development of narrow-gap welding goes back to the early 1960's when low-alloy steels having superior mechanical properties appeared. These steels had weldabilities such that low heat input and low interpass temperatures were required to obtain good mechanical properties in the weld and heat-affected zone (HAZ). Design engineers immediately accepted them for structural and pressure vessel applications because pressures and vessel diameters could be increased without further increasing wall thickness. However, the low heat input requirement imposed by the weldability of these steels limited the cross section of the weld bead; hence, more weld passes were required to fill the joint. This increased the welding cost, nullifying the savings made through the low volume of material used, forcing fabricators to seek other ways to reduce the weld metal volume requirements for a given thickness. The first success in this field was reported in 1966 by workers at the Battelle Memorial Institute (2) who successfully deposited a one-sided weld in a 50 mm (joint gap 6.25-9.5 mm) thick HY-80 plate by using the gas-metal-arc welding (GMAW) process. This technology is now in use in Europe and Japan as a result of the considerable progress that has been made since 1966.

Compared to conventional welding, a narrow-gap process offers the following advantages:

1. Less volume of weld metal is required which means a reduction in welding time, less distortion and less repair time (Fig. 1).
2. Joint preparation time and costs are reduced.
3. A constant gap width through the whole joint filling operation means that a reproducible weld pass is used. Thus, the welding procedure can be readily automated.

Many processes can be designated as narrow-gap type including gas-tungsten arc welding (GTAW), gas-metal arc welding (GMAW), flux-cored arc welding (FCAW), electroslog welding (ESW), electrogas welding (EGW), submerged-arc welding (SAW) and electron beam welding (EBW). These processes are all well documented in the literature (3). There is a general consensus among fabricators that, from a techno-economic point of view, GMAW, SAW and EBW are the most important of these processes.

Despite several advantages in conventional welding, SAW has not gained comparable popularity in narrow-gap welding. The main reasons for this are:

1. The hidden arc makes electrode placement with respect to the joint less precise than with open arc processes. Thus, seam tracking is critical.
2. The use of flux involves deslagging problems and a higher risk of slag inclusions, both of which affect economics and defect repair procedures adversely.

The U.S. Naval Research and Development Lab is currently developing tracking systems for submerged-arc narrow-gap systems and, although the work is still in an experimental stage, success is anticipated (4). In Czechoslovakia, a fluoride-rich flux has been developed which minimizes the slag entrapment and allows for up to 5 to 6 passes to be deposited, before deslagging is necessary (5). The latest development that permits narrow-gap welding with conventional fluxes and minimizes risks from imprecise electrode placement in a hidden-arc process is the constant potential, square wave, AC power source (6). This development will be discussed in detail later in the report.

Two variations of narrow-gap submerged-arc welding are available (7): the single centre or mono-pass method [Fig. 2(a)] and the two pass layer method [Fig. 2(b)]. The mono-pass method requires a minimum of welding time; but, there are disadvantages that must be considered:

1. Because the wire position is set exactly at the centre of the gap, it cannot be used to control the side-wall penetration.
2. A relatively high heat input is needed to achieve the correct fusion conditions. This is not appropriate for low-alloy steels where satisfactory welding is dependent on low heat input.
3. Removal of the solidified slag could be a problem as it is likely to be trapped between the walls. This could add to the labour cost.

None of these problems are found in the two-pass layer method, but the welding time is approximately 50% greater. However, it is considered that the resultant increased cost is negligible when weighed against the reliability of the system. The two-pass layer technique has been found suitable for high quality welds in alloy steels which demand controlled heat input.

POWER SOURCES FOR SUBMERGED-ARC NARROW-GAP WELDING

The original automatic SAW applications utilized variable voltage, [or constant current (CC)] direct current (DC) power sources with voltage-

following wire electrode feeders. This type of power source supplies constant current which is independent of arc length (8). In these machines, when the arc length is shortened, there is an increase of current. Thus, the wire feed rate is reduced until the arc length is normal again. Reversing the situation, when the arc length is extended too far, the wire feed speed increases and equalizes the arc. Because a variable voltage head cannot accelerate or decelerate quickly enough to compensate for these speed adaptations, overrun and underrun frequently occur, particularly with small wire diameters.

In a constant voltage [also called a constant potential (CP)] machine, the voltage remains practically constant even when the current varies widely. Thus, the wire can be fed at a constant speed and the welding current (or burn-off) automatically adjusts itself to maintain the arc length, or arc voltage.

A constant wire-drive machine is simpler to build and thus less expensive. It is also a more trouble free, easier to use, set-up, and generally provides better control than a constant current, DC wire-feeder.

When higher DC currents were used or thicker materials were welded, arc blow also became a problem. Users reverted to alternating current (AC) power, but constant current (or droopers as they are frequently called) were employed as there were no suitable AC/CP power sources available. Because users were accustomed to the good control obtained with DC/CP machines, it is natural that there should be a desire for an AC/CP power source.

During the 1960's, considerable work was done on AC/CP power sources for the electroslog process. They were successful once the molten flux reached a depth of 12-18 mm. At this point the arc would become smooth, and a true CP mode was experienced in the range of 40 to 60 V. However, the use of an AC/CP power source for SAW was not very successful until a few years ago because of the sinusoidal nature of the AC current/voltage source - Fig. 3. For example, as the AC current falls towards zero (c-d), the arc extinguishes (at d). The polarity of the source changes at (e), while the wire continues to advance. Wire advance continues until it touches the puddle or ionized gas and completes the circuit to the workpiece. The point on the voltage wave form at which the wire strikes is random and uncontrollable. Should it strike at a peak voltage (b), it may reignite satisfactorily. If, however, the contact occurs at some point between (d) and (f), there is very little forcing voltage available for instantaneous current build up. The power delivered is low because the short circuit presents a low voltage situation. The current

may eventually build up through the inherent inductance of the system, but this will not produce a smooth arc. To eliminate the above problem, Miller Electric Manufacturing Company (9) developed a square wave constant potential power source that operates at 30 to 40 V RMS with positive arc reignition each half cycle. Polarity change transitions are very rapid with this equipment (Fig. 4). The power source consists of a transformer which converts primary 575 V single-phase input power to 92 V secondary open circuit voltage which has various controls. Four thyristors and a memory core (or square wave inductor) are controlled to provide an essentially square wave current. Each cycle is adjustable in amplitude with very rapid zero crossing. The transition time is in the range of 80 to 150 microseconds - many times faster than the sine wave reversal time. The inductor is capable of storing vast amounts of energy. The silicon controlled rectifier (SCR) firings are timed to deliver this energy into the arc, including the delivery of a voltage equal to the instantaneous voltage of the utility supply at that point in time, even though the average arc voltage may be considerably lower. It is this ability to generate high restriking voltages on demand, with a basically low voltage regulated source, that permits the running of constant-potential mode SAW with an alternating current.

From a review of the literature above (1-7), it is clear that narrow-gap welding has certain advantages, particularly for the welding of heavy sections. Although fabricators in Japan and Europe have employed narrow-gap techniques extensively for the joining of pressure vessel rings, most of them have used variations of the gas-metal arc welding process. Therefore, the aim of this work is to develop a submerged-arc welding technique for narrow-gap welding of 200-250 mm thick 2.25 Cr - 1 Mo steel by using the newly developed AC/CP square wave power source.

EXPERIMENTAL PROGRAM

The first task was to install the Miller AC/CP square wave system and make it operational. Proper accessories were obtained to accomplish this task, and a number of attachments and modifications were made. In order to understand the operating behaviour and capabilities, the power source was evaluated for its current/voltage characteristics. It was found that the equipment could deliver 150-1000 A at 23-60 V without fluctuations (Fig. 5). The details of how the power source was attached, the modifications that were made to the link-up and an evaluation of the power source are given in Appendix 1.

Two fluxes, Linde 80 (fused) and Oerlikon OP121TT (agglomerated) were evaluated in conjunction with Linde 81 (EM 12 K) wire. The joint preparation is given in Fig. 6(a). It was found that the arc ran smoothly, and slag could

be detached easily in both cases. The agglomerated flux produced beads with a better surface appearance, however, when this flux was inadequately dried, welds made with this flux exhibited a considerable amount of porosity. None of the other problems (e.g., slag entrapment, lack of side wall fusion etc.) were observed.

There are a few operational difficulties that still remain to be solved, particularly in the arc starting. Nevertheless, a sound narrow-gap weld in a 25 mm thick plate has been successfully deposited and details of the weld with a macrograph are shown in Fig. 6 with welding parameters given in Table 1.

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Table 1 - Welding procedure for narrow-gap welding.

Wire - 3.2 mm ϕ Linde 81 (EM 12 K)

Flux - Linde 80 (fused)

AWS Class - F62, F72 - EM 12 K

Pass No.	Current A	Voltage V	Wire feed speed (mm/s)	Travel speed (mm/s)	Electrical stick-out (mm)
1	640	34	35.0	8.5	25
2	635	34	35.0	8.5	25
3-15	630	34	34.0	8.5	25

Comments: 1) Run-in speed was set at 40% of welding wire feed speed.
ii) Voltage sensing lead was attached to welding restraining jig as close to weldment as possible.
iii) Wire feed speed was recorded with a hand-held digital WFS meter (IPM).

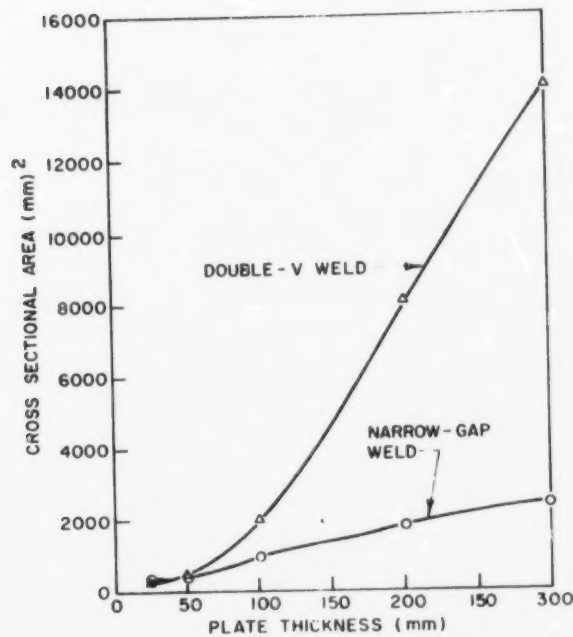


Fig. 1. Effect of plate thickness on the cross-sectional area of the weld. (neg 9479)

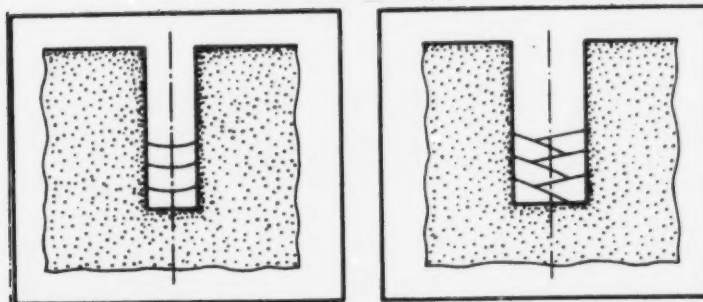


Fig. 2. Types of submerged or narrow gap welding. (neg 8732)
(a) single centre pass (b) two pass layer.

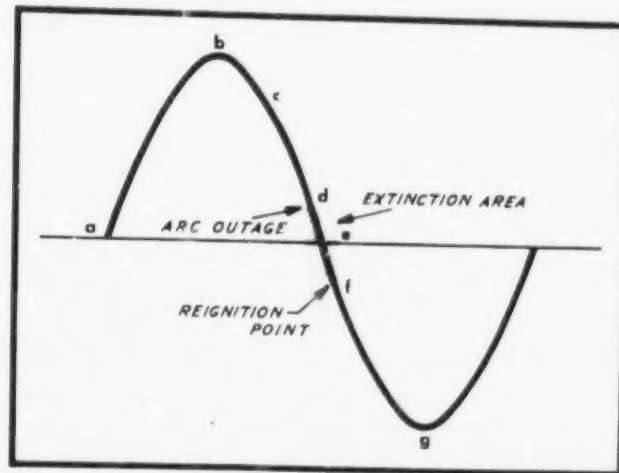


Fig. 3. Conventional sine wave current. (neg 8733)

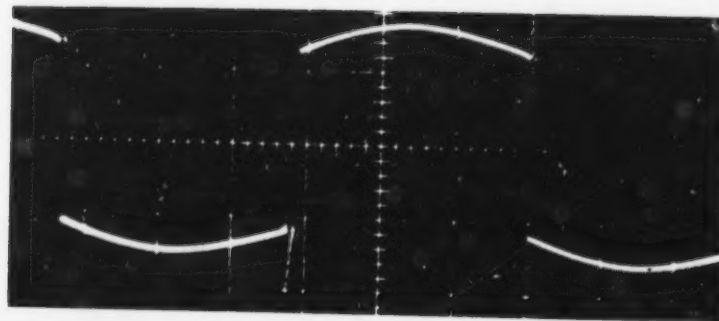


Fig. 4. AC/CP square-wave current. (neg 8734)

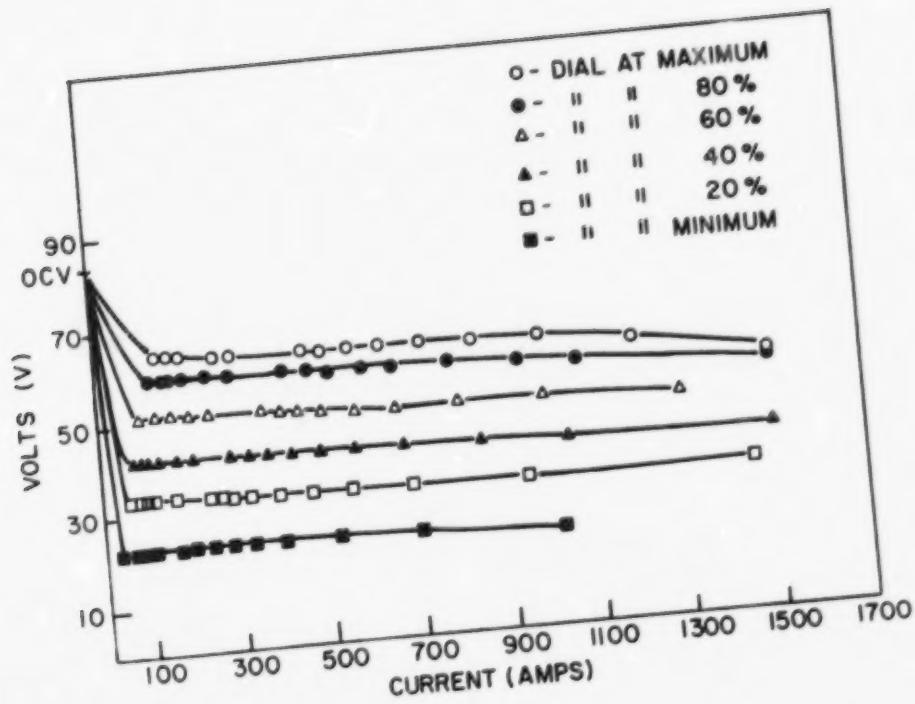
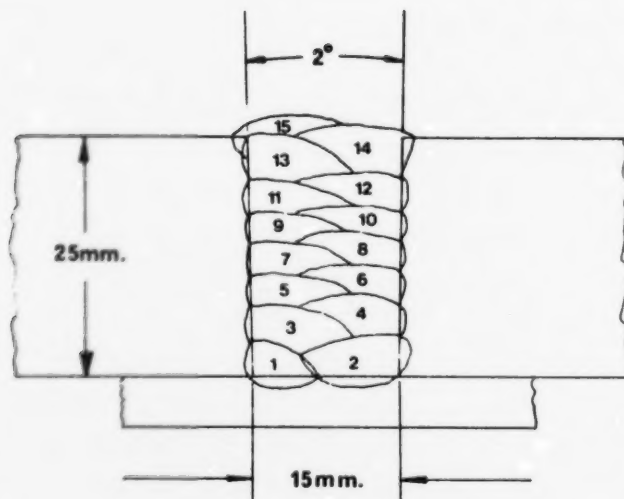
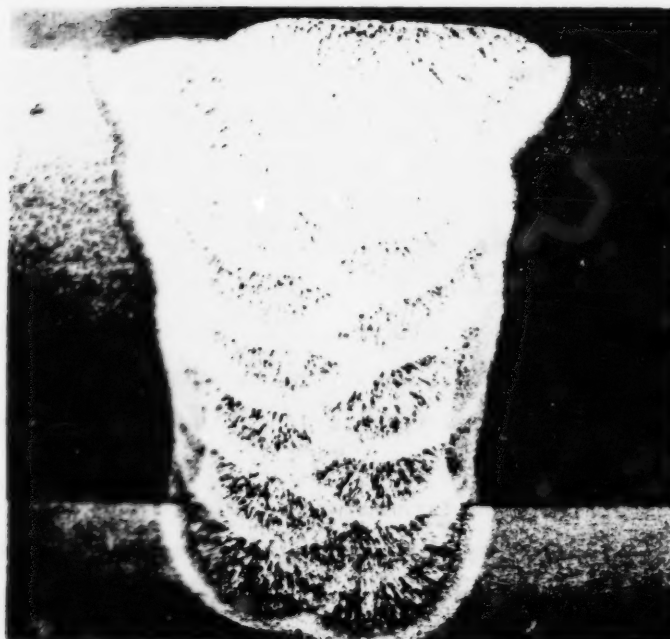


Fig. 5. I-V characteristic of square-wave power source.
(neg 9481)



(a) (neg 9480)



(b) (neg 9489)

Fig. 6. (a) Joint design, welding sequences; (b) completed weld.

APPENDIX 1

COMMISSIONING EQUIPMENT

Installation of an AC/CP Miller square-wave submerged-arc system commenced in mid April 1982 with preparation of the location of the narrow-gap system and the travel carriage and beam being anchored into place.

Because the input power requirements were satisfied prior to delivery of the equipment, there was only a need for electrical connection of the power source before complete assembly could be started.

The entire system was reviewed, and designs for mounting the components were proposed and evaluated. A visit to Canadian Liquid Air in Montreal provided a first hand view of a similar narrow-gap installation. Mounting brackets and fixtures were designed and fabricated to suit the travel carriage and beam. The control head, current-sensing box, wire-reel support and drive-roll motor were conveniently located and mounted onto the travel carriage. Once all the components were mounted, the electrical leads were connected according to instructions from the operators' manual. The system was tested without welding to ensure that all components were functioning properly and to evaluate the equipment as purchased.

After it had been demonstrated that the equipment would function properly, the control cables were modified to suit the beam, and a cable support assembly was designed and incorporated into the system. With most components mounted, the remote-control pendant and automatic flux valve were connected to the (Automatic 2) control head. The most important electrical modification was to integrate the travel carriage and welding controls so proper welding sequencing would be obtained.

The other modifications necessary to complete the installation were:

- i) to have copper extension nozzles machined to increase the length of the welding torch and thus allow thicker materials to be welded;
- ii) to install a track switch which allows for automatic shut down of the system at the termination of a weld;
- iii) to design and fabricate a flux nozzle for dispensing flux into a narrow gap; and
- iv) to fabricate an adjustable table that would serve both as a restraining jig and allow for vertical adjustment to accommodate a wide range of material thicknesses.

EVALUATION OF OUTPUT CHARACTERISTICS

The output V-I curves of the square wave AC 1000 were recorded by using a variable resistance terminal that consists of a unit designed to produce varying loads for a given input.

Recording and plotting of the voltage vs current data gives a graphical representation of the output characteristics of a power source. This information is acquired in order to know the capabilities of a given power source. The AC 1000 produced a constant potential output for all voltage settings, thus ensuring that the power source will deliver the output required for most welding applications.

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